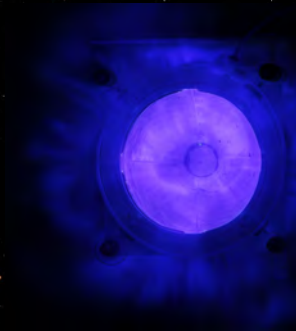


Performance of a Conical Inductive Pulsed Plasma Thruster at Multiple Cone Angles



Ashley K. Hallock



YETISPACE

Kurt A. Polzin
Adam C. Kimberlin
NASA MSFC

Outline of Talk



Inductive Pulsed Plasma Thrusters

Outline of Talk



Inductive Pulsed Plasma Thrusters



Operation

Outline of Talk



Inductive Pulsed Plasma Thrusters



Operation



What is the optimum coil geometry?

Outline of Talk



Inductive Pulsed Plasma Thrusters



Operation



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Model

Outline of Talk



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Experiment

Outline of Talk

Inductive Pulsed Plasma Thrusters

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Impulse Measurements

Outline of Talk



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Time-integrated Photographs

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Discussion of Experimental Results

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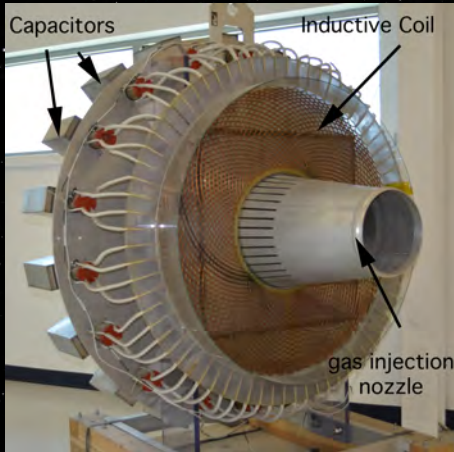
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Inductive Pulsed Plasma Thrusters

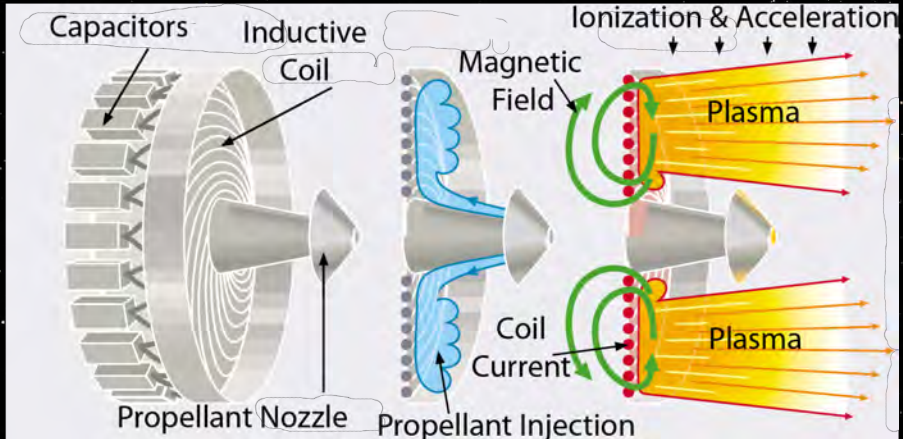
Pulsed Inductive Thruster (PIT)

PIT Mark VI :

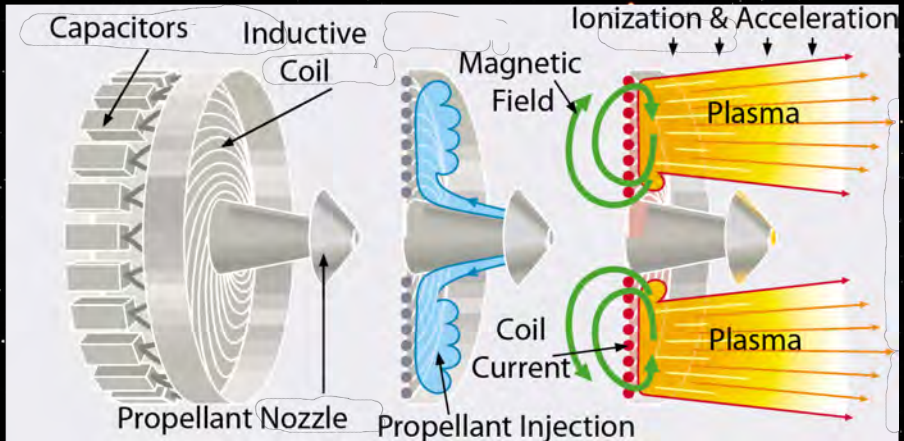


Inductive Pulsed Plasma Thruster Operation

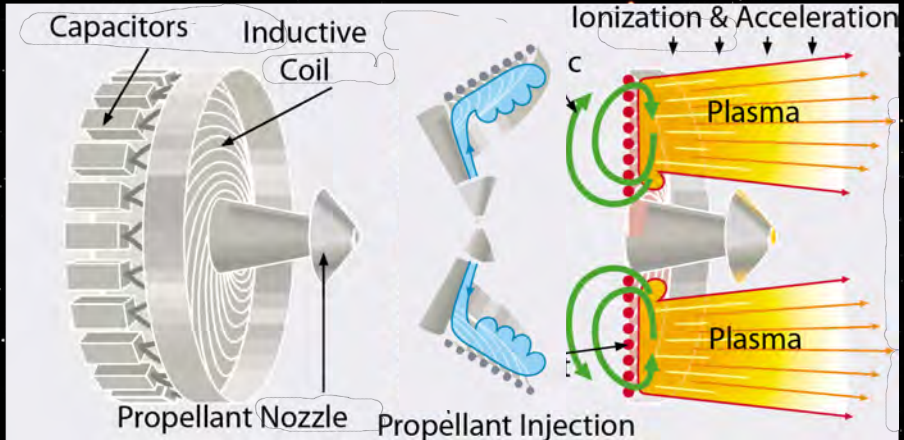
Idealized thruster operation :



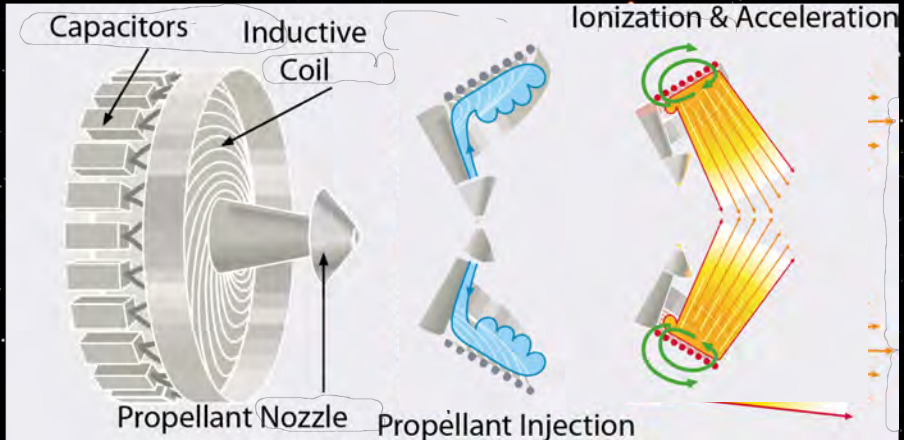
Question: What is the Optimum Coil Geometry?



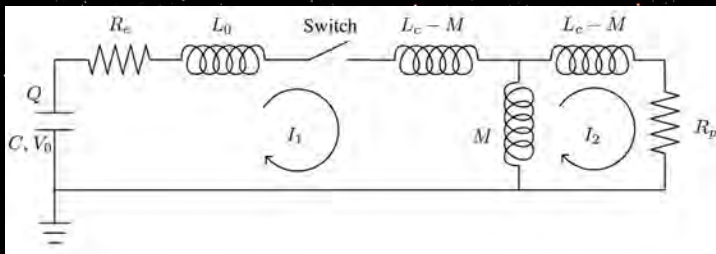
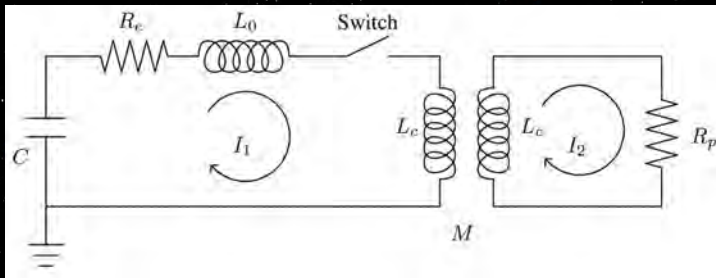
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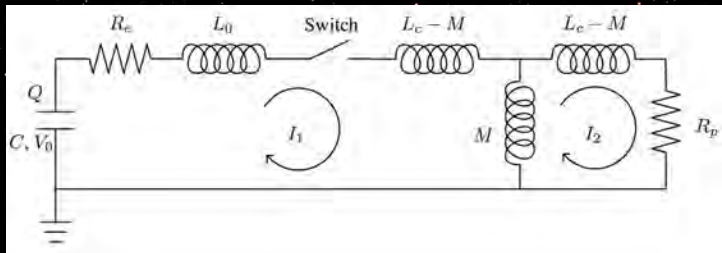
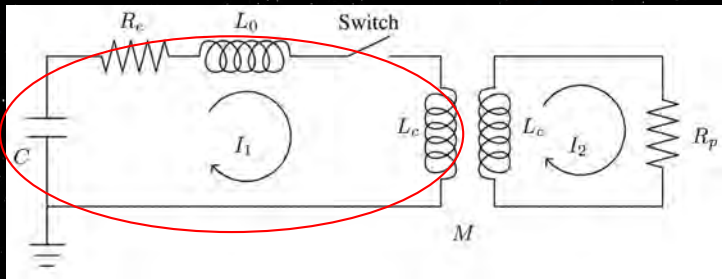
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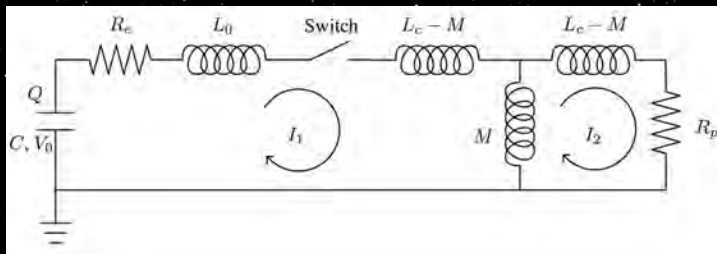
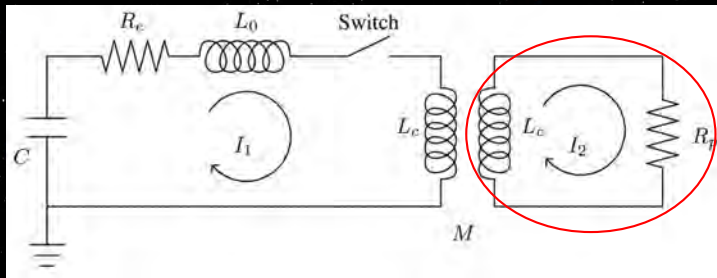
Circuit Model of Inductive Pulsed Plasma Acceleration



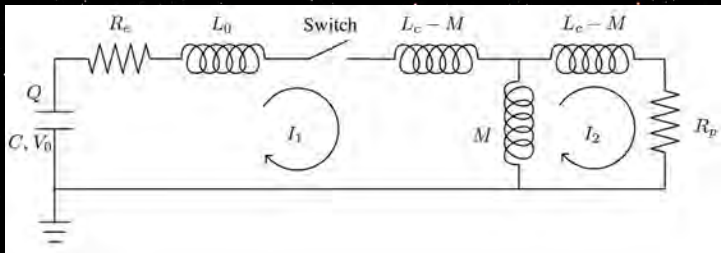
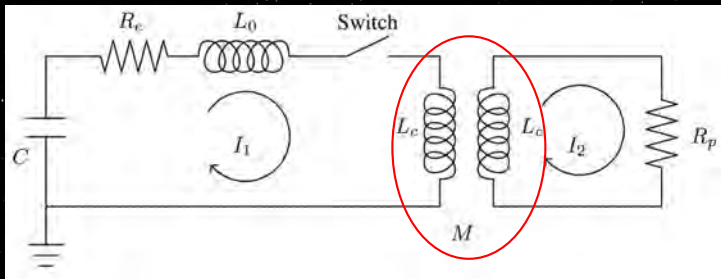
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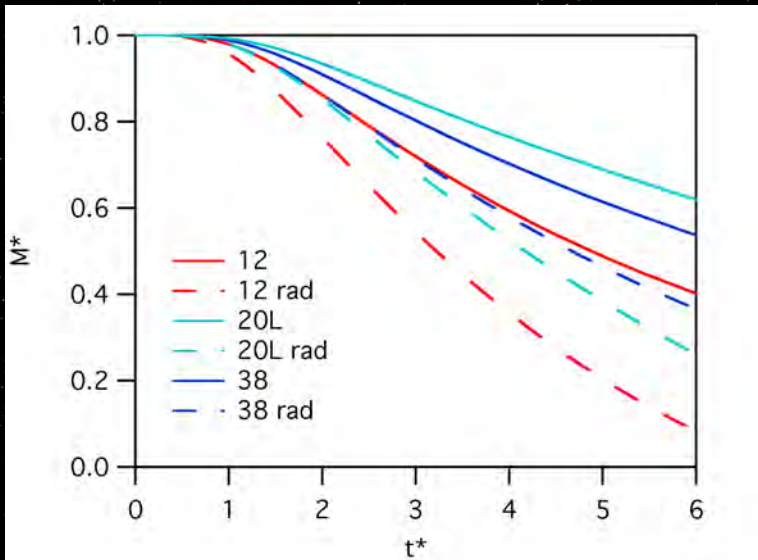
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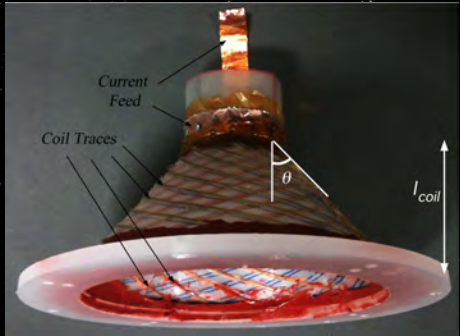
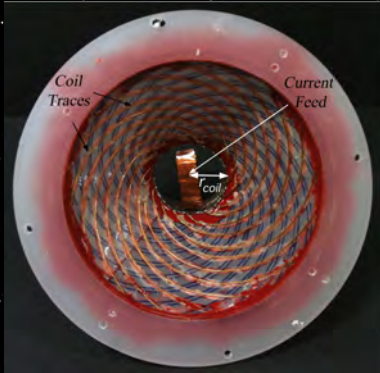


Radial Motion Accelerates Decoupling and Decreases Energy Transferred

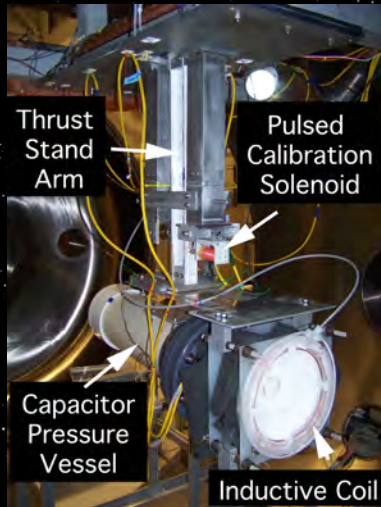


Experiment

Conical Inductive Coil for Increased Propellant Utilization Efficiency

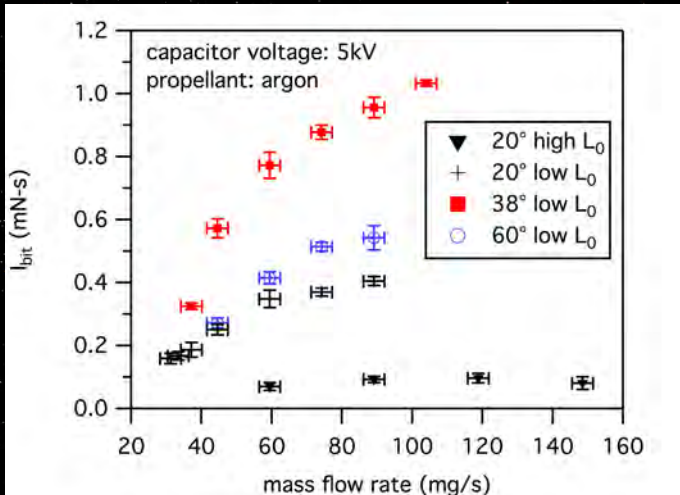


Thruster on Thrust Stand

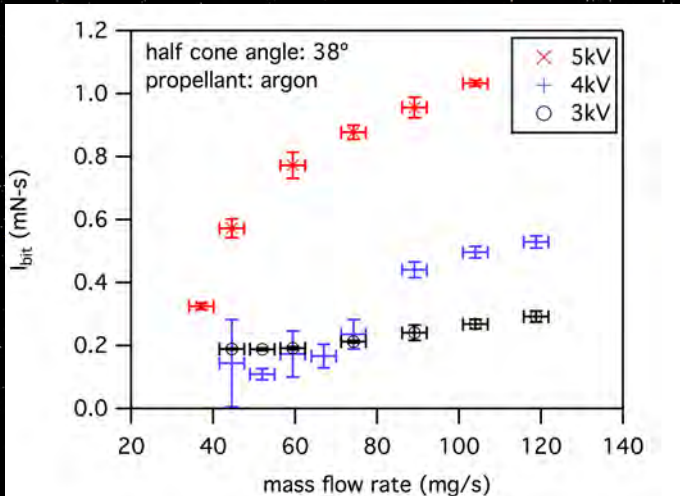


Experimental Results: Impulse Measurements

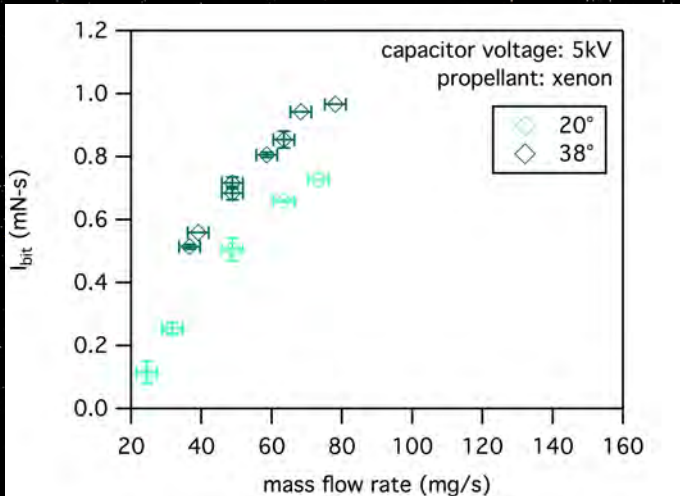
Impulse Bit Calculations for 20°, 38°, and 60°



Impulse Bit Calculations for 38° operating at 3, 4, and 5 kV



Impulse Bit Calculations for 20° and 38° operating on xenon



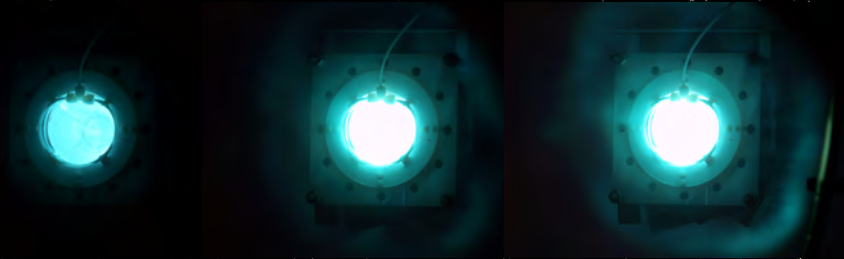


Experimental Results: Time-integrated Photographs

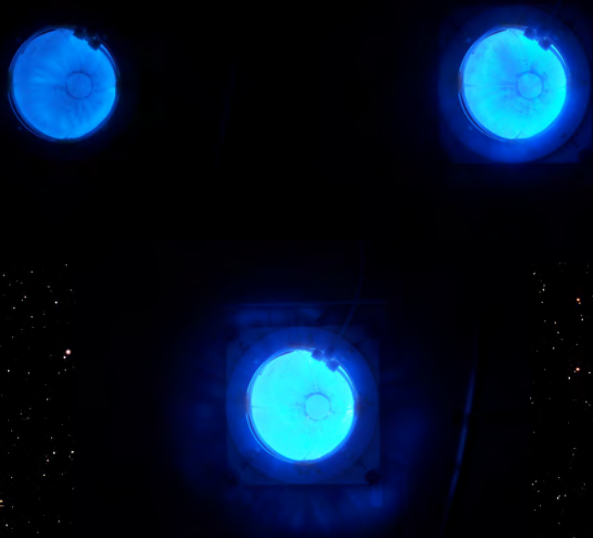
Varying mass flow rate of argon with 20°



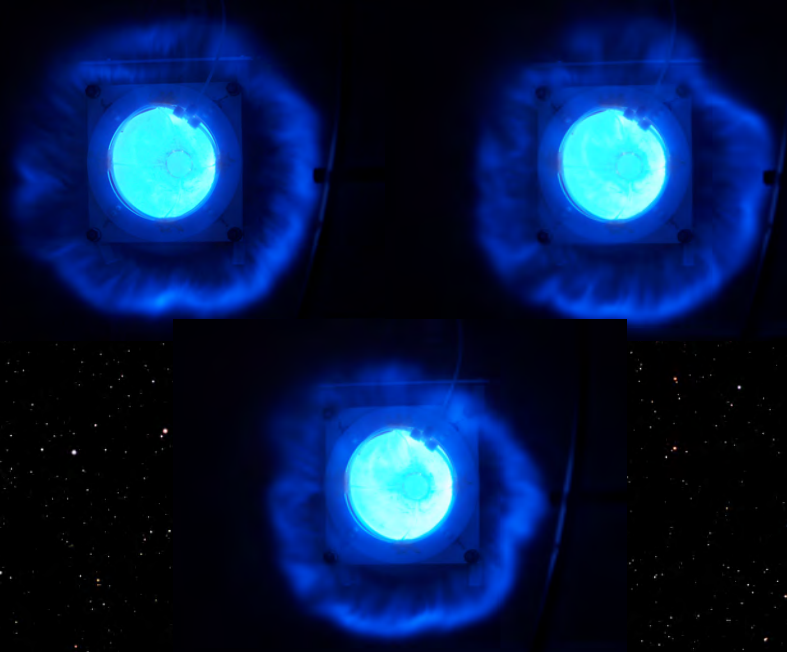
Varying mass flow rate of xenon with 20°



Varying mass flow rate of argon with 38°



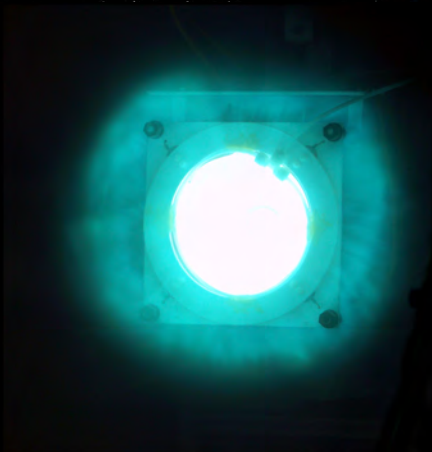
Varying mass flow rate of argon with 38°



Varying mass flow rate of xenon with 38°

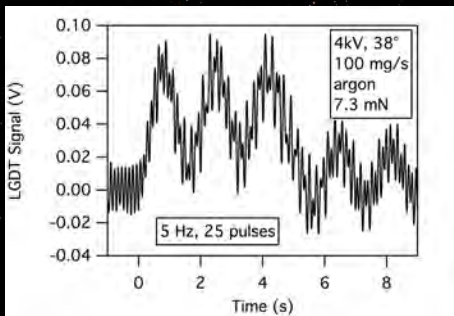
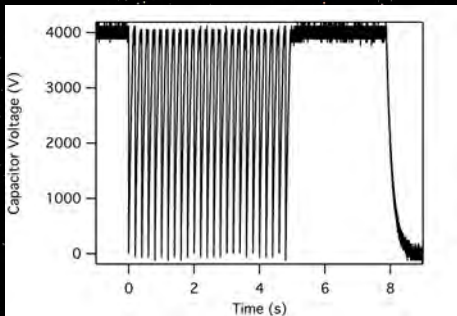


Time-resolved Video of xenon with 38°

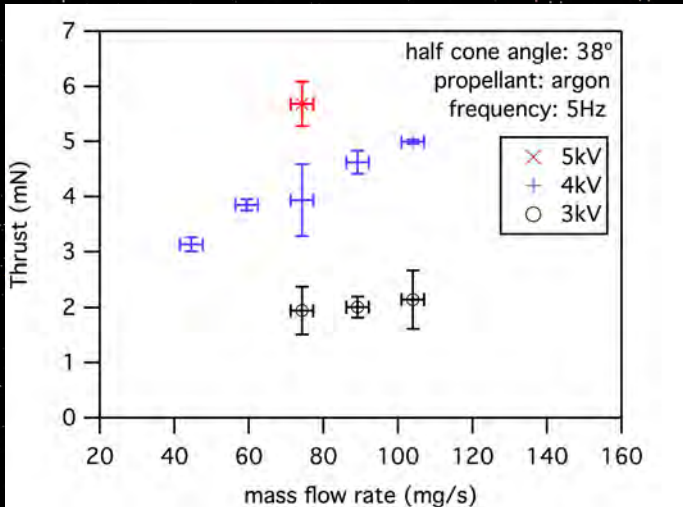


Operation at 5 Hz: Thrust Measurements

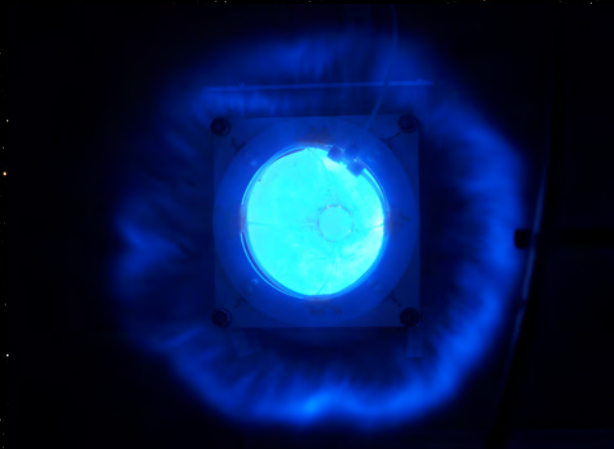
Voltage and Thrust Stand Displacement for 38°



Thrust Calculations for 38°

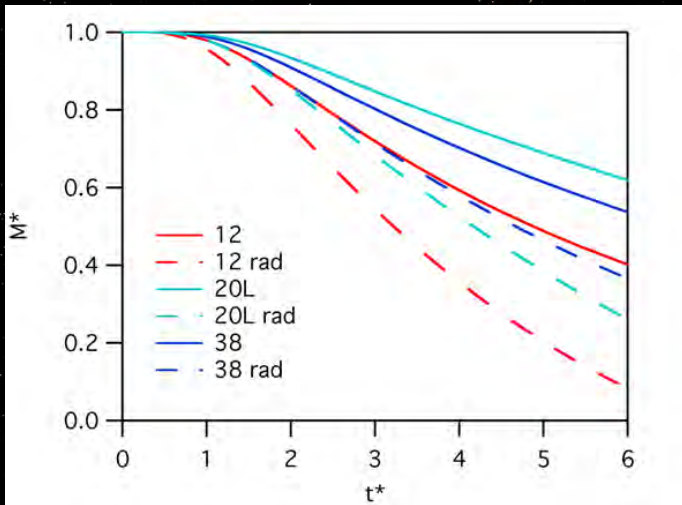


Video of 5 Hz operation with 38° on argon

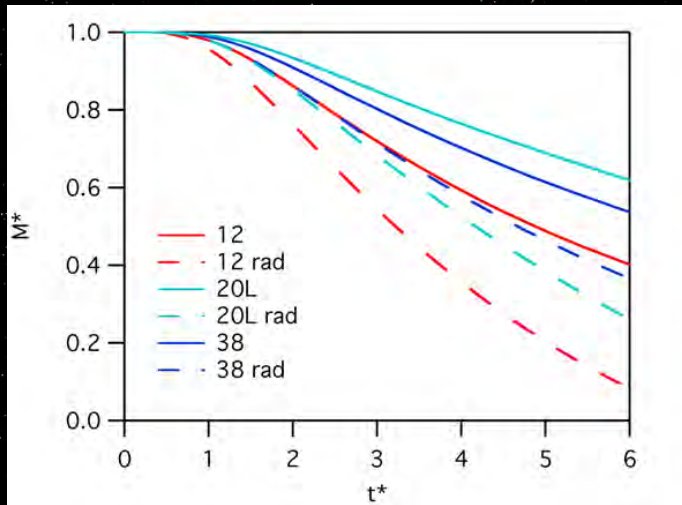


Discussion of Experimental Results

Previous analytical results suggest radial motion is detrimental to thrust



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Result: Intermediate angle produced highest thrust

Conclusions

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Conclusions

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- ✧ Thruster with 38° half cone angle produced the highest impulse overall
- ✧ Gas dynamics may have same or higher influence on performance as electrodynamics
- ✧ As of now only electromagnetics are quantified
- ✧ Next step could be quantifying gasdynamics and optimizing propellant injection

Acknowledgments

- ✧ Dr. Adam Martin, Mr. Jim Martin, Mr. Richard Eskridge, Dr. Noah Rhys, Mr. J. Boise Pearson
- ✧ NASA Advanced In-Space Propulsion Program managed by Dr. Michael LaPointe
- ✧ OCT In-Space Propulsion Program Managed by Mr. Timothy Smith



Questions?

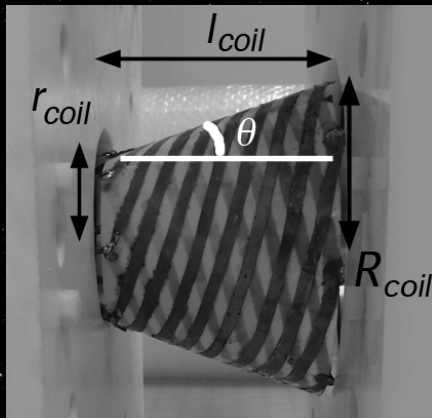
Governing Equations via Kirchhoff's Law

$$\frac{dl_1}{dt} = \frac{L_C V - L_C R_e l_1 - M R_p l_2 + (L_C l_2 + M l_1) \frac{dM}{dt}}{L_C (L_0 + L_C) - M^2}$$

$$\frac{dl_2}{dt} = \frac{M \frac{dl_1}{dt} + l_1 \frac{dM}{dt} - R_p l_2}{L_C}$$

$$\frac{dV}{dt} = -\frac{l_1}{C}$$

Definition of a Radial Location



$$\bar{r} = 1/2 (r_{minor} + R_{major})$$

$$\overline{r_{coil}} = 1/2 (r_{coil} + R_{coil})$$

2-D Equations Governing Current Sheet Coupling

$$L_{tot} = L_0 + L_C - \frac{M^2}{L_C}$$

$$L_{tot}(\bar{r}, z) = L_0 + L_C \left(1 - \exp(-z/z_0) \left(\frac{\bar{r}}{r_{coil}} \right)^N \right)$$

$$M = L_C \exp\left(-\frac{z}{2z_0}\right) \left(\frac{\bar{r}}{r_{coil}} \right)^{N/2}$$

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Equations Governing Current Sheet Motion

$$\frac{dv_z}{dt} = \frac{\left[\frac{L_C I_1^2}{2z_0} \exp\left(-\frac{z}{z_0}\right) \left(\frac{\bar{r}}{r_{coil}}\right)^N \right]}{m_{bit}}$$

$$\frac{dv_r}{dt} = \frac{\left[P_2 2\pi \bar{r} I_{coil} - \frac{L_C I_1^2 N}{2\bar{r}_{coil}^N} \exp\left(-\frac{z}{z_0}\right) (\bar{r})^{N-1} \right]}{m_{bit}}$$

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